#noviembreHD. Cuarto congreso de la Asociación Argentina de Humanidades Digitales (AAHD). Asociación Argentina de Humanidades Digitales, Buenos Aires, 2021.

Social Network Analysis in the History of Sciences: Visualising Sociability in Scientific Expeditions with Gephi.

Anderson PEREIRA ANTUNES.

Cita:

Anderson PEREIRA ANTUNES (2021). *Social Network Analysis in the History of Sciences: Visualising Sociability in Scientific Expeditions with Gephi. #noviembreHD. Cuarto congreso de la Asociación Argentina de Humanidades Digitales (AAHD). Asociación Argentina de Humanidades Digitales, Buenos Aires.*

Dirección estable: https://www.aacademica.org/noviembrehd/24

ARK: https://n2t.net/ark:/13683/ehed/GFz

Social Network Analysis in the History of Sciences: Visualising Sociability in Scientific Expeditions with Gephi

Análisis de redes sociales en la Historia de las Ciencias: Visualizando la sociabilidad en expediciones científicas con Gephi

Coordinación

Gimena **del Rio Riande**

Romina **De León**

Anderson PEREIRA ANTUNES[1]
anderson.p.antunes@gmail.com
Museu de Astronomia e Ciências Afins
https://orcid.org/0000-0001-7133-7848

ABSTRACT

With its origins in Sociology, social network analysis has gained popularity with the development of both Digital Humanities and free network visualization software, such as Gephi. For the History of Sciences, network analysis can highlight how scientific knowledge is socially constructed and dependant on the interactions between individuals and institutions. In this paper I demonstrate how the analysis and visualization of networks with Gephi can be a valuable tool to understand the sociability of 19th century scientific expeditions by investigating Louis Agassiz's and Henry Walter Bates' travels in Brazil.

KEYWORDS

Social Network Analysis, Network Visualization, Gephi, Louis Agassiz, Henry Walter Bates.

RESUMEN

Con sus orígenes en la Sociología, el análisis de redes sociales ha ganado popularidad con el desenvolvimiento de las Humanidades Digitales y de software gratuitos de visualización de redes, como Gephi. Para la Historia de las Ciencias, el análisis de redes puede destacar cómo el conocimiento científico es construido socialmente y depende de interacciones entre individuos e instituciones. En este artículo demuestro cómo el análisis y visualización de redes con Gephi puede ser una herramienta valiosa para comprender la sociabilidad de las expediciones científicas del siglo XIX al investigar los viajes de Louis Agassiz y Henry Walter Bates por Brasil.

PALABRAS CLAVE

Análisis de redes sociales, visualización de redes, Gephi, Louis Agassiz, Henry Walter Bates.

AAHD - 2021
Vol. 1 - N° 2

ISSN
2718- 7470

1. INTRODUCTION

Social network analysis, or SNA, was first developed by sociologists who were interested in investigating social structures and the ways individuals related to each other in society. According to Luke and Harris (2007), early examples of what would later become social network analysis can be found in the works of 19th century sociologists such as Auguste Comte (1798-1857) and Georg Simmel (1858-1918). However, it was only halfway through the 20th century that SNA really began to gain popularity as an analytical tool even outside Sociology.

Some of this popularity was due to Jacob Levy Moreno's (1889-1974) work in psychosociology. In the 1930s, seeking to understand how belonging to certain social groups could affect individual behaviour, Moreno proposed to analyse the degree to which individuals were influenced by their relationships in a network by drawing these relationships on a graph. Mathematics and graph theory greatly influenced his thinking and continue to play a substantial part in social network visualisation today. Moreno's graphs were named *sociograms* and formed the basis for what he called *sociometry*, an attempt at quantitatively understanding social dynamics. The way he represented social relationships formed the foundation for later visualisation tools and, because of this, Moreno's sociograms can be considered an important step in the development and popularisation of SNA. In a sociogram, individuals in a group are represented by circles, also called nodes, and the lines, or edges, which connect these circles together indicate the existence of a social relationship linking these individuals (figure 1).

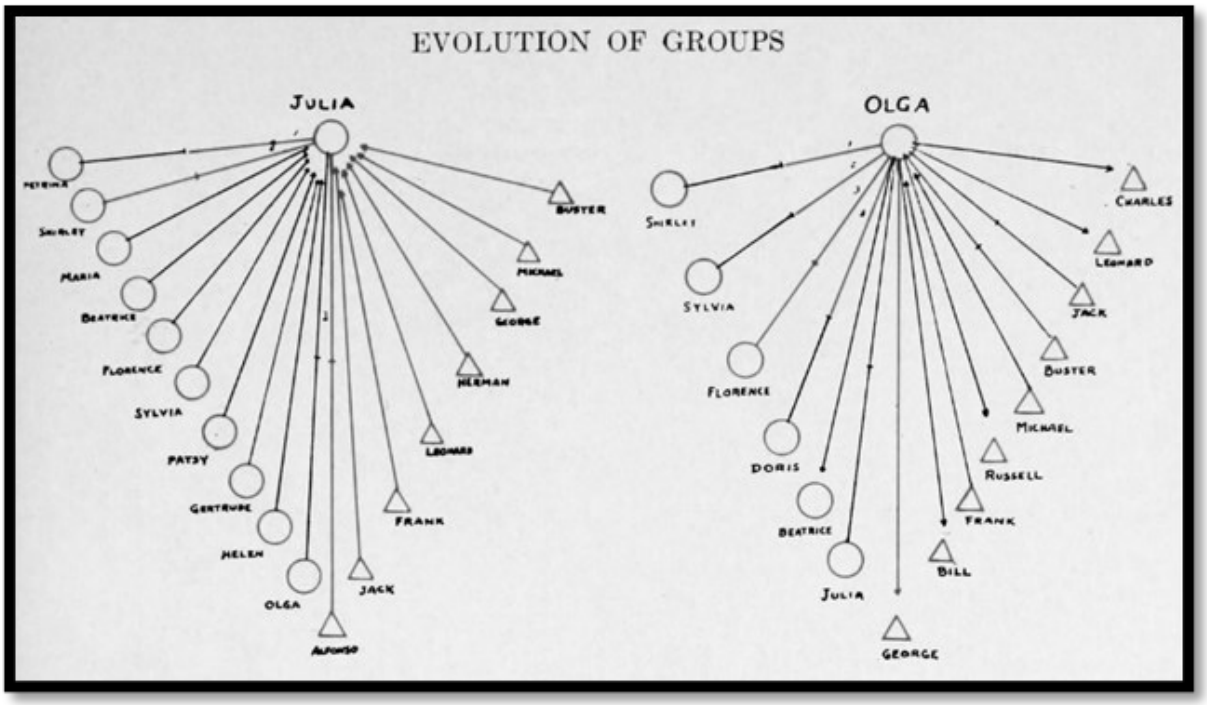

Figure 1. Jacob Levy Moreno's sociograms. Source: Moreno (1934, p. 45).

[1] PhD in the History of Science at Casa de Oswaldo Cruz/Fundação Oswaldo Cruz. Currently working at the History of Science department of Museu de Astronomia e Ciências Afins with a scholarship from the Ministry of Science's Programa de Capacitação Institucional scheme.

Moreno's sociograms can also be considered a milestone in SNA, as they showed how graphs can be used as analytical tools for understanding social interactions. Since they allow a new way to approach information, network graphs can also be important tools for communicating results obtained from SNA, as they translate complex social dynamics into images that can catch the public's attention and can be intuitively read. Given the growing importance of visual learning (Bradford, 2004; Ma et al., 2012), especially with digital media and the internet, graphs can also be an effective way of communicating a research's results to lay audiences on online social network platforms. This has been increasingly the case of Journalism, which has been relying more on infographics to present complex and specialised information to the public (Zacks et al., 2002).

Throughout the 20th century, further developments promoted SNA as an important analytical tool. In the 1960s, a group led by sociologist Harrison White at Harvard University innovated by applying mathematical models to social structures in what was later called the *Harvard Revolution* (Chen, 2020). The foundation of specialised professional associations, such as the International Network for Social Network Analysis, in 1978, were also important landmarks in the institutionalisation of SNA. For authors such as Otte and Rousseau (2002), the 1980s can be considered an especially relevant time in the expansion of SNA outside of Sociology, partly due to the technological advancements that made personal computers more largely available to researchers and facilitated the analysis of large amounts of data.

More recently, with the development of Digital Humanities (Gold, 2012), many researchers have started using network visualisation software such as Gephi[2], Cytoscape[3], Pajek[4], NodeXL[5], among others, as part of their methodologies. The open-source nature of some of these software means that researchers can modify the software's code to add new functionalities based on specific research needs, increasing the potential uses of new technologies as analytical tools in the Humanities. The availability of open-source network visualisation tools has been another element in the popularisation of SNA. In this article, I will discuss how social network analysis can be used in the History of Science by presenting my experience using Gephi to investigate the sociability of 19th century scientific expeditions looking at the networks of local collaborators involved with Louis Agassiz's (1807-1873) and Henry Walter Bates' (1825-1892) travels in Brazil.

2. SOCIAL NETWORK ANALYSIS IN THE HISTORY OF SCIENCES

According to Vermelho, Velho and Bertoncello (2015), it was in the field of Economic History that historians first began to use the concept of networks. But, unlike sociologists, these historians were not initially looking at social networks, but instead, they aimed to understand how transport networks enabled the movement of goods and products between different regions in the context of the expansion of global capitalism. In the authors' own words:

[2] Open-source software available on: https://gephi.org/.
[3] Open-source software available on: https://cytoscape.org/.
[4] Open-source software available on: http://mrvar.fdv.uni-lj.si/pajek/.
[5] Free and paid licenses, available on: https://www.smrfoundation.org/nodexl/.

> Networks are in the very essence of the capitalist market economy which, in a first moment, connected the source of natural resources with the production centres (industry) using railways, a system by which raw materials circulated into production centres. Circulation networks also connected markets and goods multiplying the trading potential of this economic model (p. 869, *translated for this article*).

This initial approach through Economic History meant that some of the first networks analysed by historians were merchant or trade networks. In these networks, trading stations and navigation companies connected different regions in a world profoundly marked by the relations between metropolises and colonies. A pioneering example of this type of analysis is Sanjay Subrahmanyam's *Merchant Networks in the Early Modern World, 1450-1800* (1996), in which the author identified that some individuals in a network had the special characteristic of acting as intermediaries, connecting different peoples and cultures, and making economic trading possible. Despite not using visualisation tools or graph theory, Subrahmanyam's work was among the first to divert historians' attentions towards the analysis of social networks. According to Antunes (2012):

> Subrahmanyam has made an unquestionable contribution to historiography and his work has brought historians' attention to social network analysis as a work instrument. For this reason, despite not having actually applied SNA to obtain the results of his work, he has decidedly provided an incentive to include social networks in 21st century historiography, promoting it to the category of historical analysis (p. 17, *translated for this article*).

Another important work published at around the same decade was Padgett and Ansell's *Robust Action and the Rise of the Medici, 1400-1434* which first appeared on the *American Journal of Sociology* in 1993. In it, the authors studied the relations between the different families that were part of the Florentine elite during the first half of the 15th century. Their findings led them to propose that the centrality the Medici family had in Italian society was explained by their connections to other families, usually by marriage or commerce. Well planned social ties were the key to their social prominence. It is interesting to notice that even though Padgett and Ansell did not intend to use Moreno's sociograms, the network visualisation they created bear a striking resemblance to what was proposed by Moreno's sociometry years before. The graph created as a result of their research shows how the Medici family occupied a central position among other wealthy Florentine families at the time, being connected to them by lines which represent different kinds of relations (figure 2). The more connections one has in a social network, the more central their position will be in the graph.

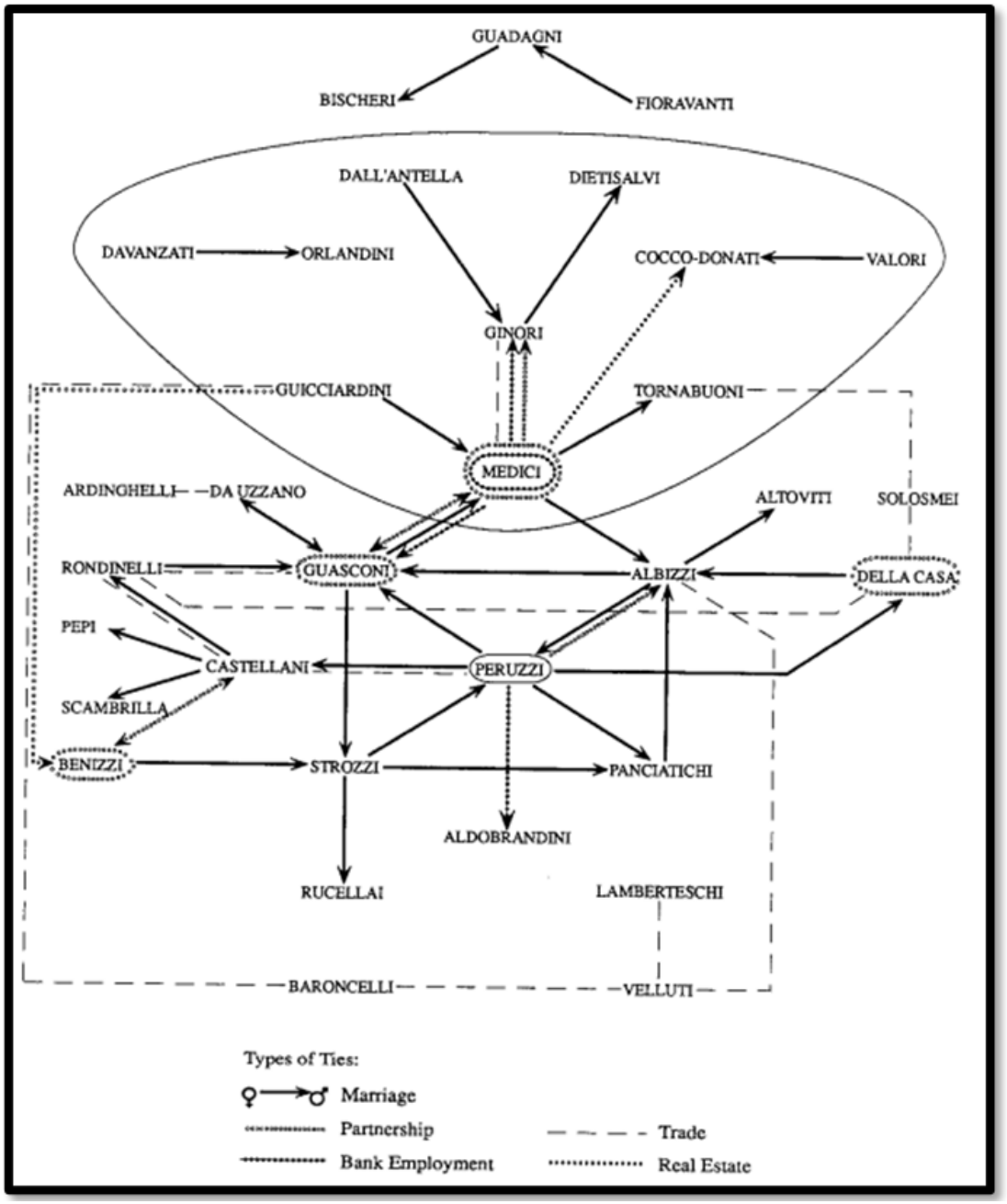

Figure 2. Social relations between Florentine families in 15th century Italy. Source: Padgett and Ansell (1993, p. 1276).

Both Subrahmanyam's and Padgett and Ansell's works demonstrate how historians started to turn their focus to social networks, especially in the 1990s. Some decades later with the popularisation of personal computers and the development of open-source network visualisation software, more historians have started to implement network approaches to studies not only in Economic History, but in all fields of historical research. Highlighting the advantages of SNA in historical studies, Mathias (2014) points out that:

> Being a valuable methodological-analytical instrument, social network analysis can be used both in the study of societies or individuals at any given time. Given the current popularity of Italian micro history, we believe that its use in conjunction with social network analysis can offer an important contribution to the (re)interpretation either of the logic behind how societies work, or of individual strategies and actions. This is possible because social network analysis gives us an opportunity to understand the nature of social connections both at macro and micro levels, helping to clarify the strategies and behaviours of individuals, institutions, etc. (p. 142, *translated for this article*).

There are currently numerous projects on the web utilising network visualisation software for historical research. One of the best-known examples is Stanford and Oxford Universities' *Mapping the Republic of Letters*[6] in which letters sent and received by European and North American intellectuals are used to map their social interactions, illustrating the circulation of ideas between minds like Galileo (1564-1642), John Locke (1632-1704), Voltaire (1694-1778), among others.

The possibilities and the success obtained from social network analysis and visualisation to study historical records led to the creation of two sub-projects: *British architects on the Grand Tour in Eighteenth century Italy*[7] and *An intellectual map of Science in the Spanish Empire, 1600-1810*[8]. In these projects historians are using correspondence exchanged by intellectuals around the globe to understand their social networks, mapping their contacts, and overlapping this graph over geographical maps of the world, giving the public an immediate and clear understanding of how far ideas travelled (figure 3). By joining network visualisation and cartography, researchers can better observe and understand the transnational character of knowledge circulation in the Early Modern period.

Figure 3. Map showing the different localities where Voltaire's correspondents were located between 1700 and 1750. Source: Stanford University (2013).

One other important project involving social network visualisation software is Harvard University's *Visualizing historical networks*[9], which was organised by historians associated with the Cen-

[6] Available at: http://republicofletters.stanford.edu/.
[7] More information is available at: http://republicofletters.stanford.edu/publications/grandtour/.
[8] More information is available at: ~/spanishempire.html.
[9] More information on the project is available at: ~/visualizing/index.html.

ter for History and Economics. At the project's website we can see there are currently twelve different sub-projects being developed by multidisciplinary teams analysing themes such as the presence of French expatriates in Ottoman Egypt, the associations between the British Society for the Diffusion of Useful Knowledge and different institutions around the globe, and many others. All twelve initiatives are looking at social networks and using Gephi as their choice software to map and create visualisations of the networks discovered using historical sources. On the advantages of using social network analysis and visualisation, some of the project members highlight that:

> Visualizing or graphing such networks serves two overlapping ends. First, it provides a visible prosopography – a searchable reference of connections far easier to read and to use than any of the classic examples in the field. Though the networks which we are concerned with are not massive, they are still too big to comfortably hold in one's mind all at once. Second, the graphical mapping of networks makes some patterns in the data much more obvious. Such patterns may be already well understood; in these cases, a network map may serve as an ideal teaching device. Yet these patterns may be new or newly discovered. In this way, Gephi, and social network mapping more generally, can prove to be a highly useful research tool (Center for History and Economics. Harvard University, 2017).

Noticing the growing popularity of S.NA among researchers in the Humanities, and especially amid historians, Pandolfi and Bueno (2014) reviewed several projects using social network analysis and visualisation tools. According to the authors, SNA can be applied to all kinds of historical records, making it a versatile methodology that historians can use. In their review, the authors claim that:

> Finally, historians have been applying SNA to different kinds of sources. Some have been using filiation networks, in which people are connected by events. For example, in their study on social networks in Byzantine Egypt, Ruffini assumes that if two people or events are mentioned in the same papyrus, that there is some sort of connection between them (Ruffini, 2008, p. 29). Carvalho and Ribeiro (2008), on the other hand, have used 17th and 18th century post-mortem inventories and parish records for baptisms to study the meaning of godfathering in Óbidos, Portugal. Based on the metrics used in their network, they have identified in this region a "small world" structure in which people were more connected than initially supposed. In Brazil, using similar sources, Mendes (2012) has applied SNA to reconstruct godfathering and marriage alliances in the region of the Piranga valley with the goal of understanding the meaning of the personal choices people made when choosing a godfather or a spouse (p. 10, *translated for this article*).

As the authors have pointed out, many historians are using SNA with the goal of understanding how social networks allowed for social mobility, especially by choosing the right partner or godfather to their children. It is interesting to notice, however, that while many researchers are applying SNA, only a few of them are also using network visualisation software, and this number is especially low in the History of Science.

Scientific research has long been thought of as a social and collaborative practice which relies on the contributions of many different individuals and institutions. One of the most famous proponents of a social approach to scientific activity was Ludwik Fleck (1896-1961) who, on his *Genesis and development of a scientific fact* (1935), proposed that science was developed by *thought collectives*. Despite having little impact at the time of its publication, Fleck's ideas were later expanded by philosopher Thomas Kuhn (1922-1996). On *The Structure of Scientific Revolutions* (1962), he suggested that science is governed by paradigms, which determine the problems and the solutions that scientists consider acceptable. Because of this, Kuhn underlined that the way scien-

tists were educated, by manuals which presented many scientific facts and little scientific history, contributed to moulding their minds in accordance with the current paradigm in their field. In making scientists think in a determined way, paradigms direct scientific research in order that it constantly seeks to confirm and reaffirm its core principles. This, according to Kuhn, gives scientists the illusion that scientific development occurs in a linear and progressive ways when, in fact, it happened by revolutions originated in controversies that caused different paradigms to be confronted. As evidenced by Farley and Geison's (1994) study of the Louis Pasteur (1822-1895) and Félix Archimède Pouchet (1800-1872) controversy over spontaneous generation, controversies are not solved entirely based on scientific evidence, but are also dependant on the social and institutional aspects of science.

Later, in the 1970s, with the development of the Strong Programme in the Sociology of Knowledge authors such as David Bloor, Barry Barnes, John Henry, and others, started to emphasise even more the importance of analysing science with regards to its economic, political, and social context. Since then, there has been a growing number of studies focused on demystifying the apparent neutrality and objectivity of science. Today, the comprehension that science is a social product is already consolidated in the field of Science Studies. Many historians of science are nowadays investigating themes such as circulation of knowledge, the contributions of different peoples to scientific activities, such as native inhabitants during a scientific expedition or lab technicians in a more rigid institutional setting. However, even though there are many examples of current research looking into the social aspects of science, very few take advantage of network visualisation tools.

3. ANALYSIS AND VISUALISATION OF SOCIABILITY IN SCIENTIFIC EXPEDITIONS

My first experience with social network analysis took place while analysing the network of individuals who contributed to Louis Agassiz's scientific expedition to Brazil between 1865 and 1866. That research was inspired by the growing bibliography that discusses the importance of sociability to the scientific work of naturalists in the field during scientific expeditions, observing that the field was a more socially flexible space that allowed naturalists to interact with individuals with no scientific training, such as the native groups of Brazilian Amazonia. The idea of *contact zones*[10] allows us to think about Amazonia as a space where naturalists could widen their social interactions in ways which were not possible within the confines of their cabinets in European Natural History museums and scientific societies. In the field, these relations became essential to the success of scientific expeditions, not only because local inhabitants could share their solutions to the logistic challenges of travelling through territories unknown to naturalists, but because they also collaborated with the collection of specimens and shared traditional local knowledge. After studying a diverse set of 19th century travel books, Moreira (2002) highlighted the main areas local inhabitants were able to contribute to naturalists, stating:

[10] The term was coined by Mary Louise Pratt (1999) in her analysis of how individuals from different cultural, social, and geographic origins interacted despite the tensions and asymmetries of colonial spaces.

> From many of these writings you can establish the main contributions of local peoples: identification, location, collection and nomenclature of animals and plants; preparation and preservation of specimens; discovery of "new" species; analysis of habits and uses of animals and plants; geographical and meteorological knowledge, as well as knowledge of the distribution of animals and plants; anthropological information; indication of the more favourable spots for research; domestication of animals; and fabrication of instruments, including those used in the capture and preservation of animals (p. 42, *translated for this article*).

The contributions of local inhabitants to scientific expeditions were usually made invisible by the conventions of scientific writing, which still values qualities such as neutrality, impersonality, and objectivity (Camerini, 1997). However, travel books, diaries, field journals, correspondence, and illustrations made by travellers reveal the presence of a great number of local collaborators in their expeditions. One of the two expeditions chosen for analysis in this article was the Thayer Expedition, led by Swiss naturalist Louis Agassiz. It was chosen not only due to its importance and notoriety to the History of Science, but also because of the great support network that it had in Brazil. Since Agassiz was one of the best-known naturalists of his time, the expedition was able to rely on the funding of banker and philanthropist Nathaniel Thayer Jr. (1808-1883), as well as the support of the American and Brazilian governments, the latter directly on account of Agassiz's personal relationship with Emperor Pedro II (1825-1891).

An analysis of *A Journey in Brazil* (1868), which was published jointly by Agassiz and his wife Elizabeth Agassiz (1822-1907) who accompanied him, led to the identification of a total of 168 individuals directly involved with the group's investigations in Brazil. The contribution of local inhabitants was constant throughout the entire expedition, and it is particularly interesting to notice that almost half (75, or about 44% of the total) of these individuals contributed in ways that we could consider scientific, either by sharing information about the local nature or, mostly, by assisting with the collection of specimens that formed the collections later sent to the Museum of Comparative Zoology created by Agassiz at Harvard University. There has also been a large number of individuals (35, or about 21% of the total) who aided the group with the logistical aspects of travelling, such as finding lodgings and assisting them in travelling, especially through the complex waterways of Brazilian Amazonia.

The analysis of the relations between travellers and local inhabitants also reveals the disparities and asymmetries in the way naturalists interacted with the diverse group of people whom they had contact with in Brazil. The way travellers interacted with the indigenous population, with enslaved individuals, and with riverside groups in interior Brazil was different to the way they interacted with members of the local elites, especially those who had studied abroad and with other foreigners who lived in the country. This does not mean, however, that only the latter were able to contribute with important scientific information, as many indigenous and enslaved men and women aided the travellers with the location, collection, and preparation of specimens.

Also, not all individuals who participated in 19th century scientific expeditions had the same degree of involvement with the naturalists who organised them. While some were paid for their contributions, others acted voluntarily as a way of showing their own personal interest in scientific advancement or, in some cases, showcasing their superior social status. At the same time, working in

the field allowed for greater social flexibility, which meant that individuals who occupied lower positions in the local social hierarchy did not always have an inferior or lesser involvement with the expedition.

On the travel books published by naturalists, social relationships can sometimes be inferred by the choice of pronouns and adjectives used to introduce and address these individuals. We often find, for instance, that foreigners and other naturalists met in Brazil are usually referred by the English pronoun *Mr.*, while Brazilian naturalists, government officials and other socially prominent individuals locally were referred by the same pronoun, but in Portuguese, *Sr*. At the same time, it is interesting to notice that most enslaved and indigenous collaborators were usually mentioned without the use of any pronouns or qualifying adjectives, indicating their lower standing on the social hierarchy.

Identifying the individuals who make up these networks is the first step in the creation of a graph that allows us to visualise and understand how local inhabitants worked alongside naturalists. Among the many different network visualisation software available, Gephi was chosen not only because of its free and open-source nature, but also because of the large group of users who are active in forums[11] sharing their experience and helping new users to understand and use the software. More than that, Gephi also has a very user-friendly interface, allowing new users to quickly get a grasp of the software's features. It was developed in 2008 at the *Université de Technologie de Compiègne*, in France, by Mathieu Jacomy who was not satisfied with the tools available at the time for network visualisation (Heymann, 2010). It quickly gained attention, being awarded in Google's Summer of Code scheme, which helped its development during its early years. Being open-source, Gephi is also open to new additions to its source code by independent developers, which can be a great advantage to researchers, especially within the Digital Humanities[12].

The first step to use Gephi as a tool for historical analysis is consulting and analysing the historical documents which have information on the network that will be transformed into a graph. A network graph can only be drawn based on information researchers collected in their sources. For this analysis, the source material was the travel book published by Louis Agassiz and his wife. It means the graph will be able to represent the network of people involved with the Thayer Expedition according to the couple's own perception of their relationships with local inhabitants (figure 4). This means that most individuals included in this network will be related either to Louis or Elizabeth Agassiz, as they are the ones who have written about their network in a first-person narrative. For the graph, this means that the nodes representing both travellers will be some of the largest, as the

[11] Available at: http://forum-gephi.org/.
[12] See Jacomy, Bastian, and Heymann (2009), available at: https://www.aaai.org/ocs/index.php/ICWSM/09/paper/view/154.

size of each node is proportional to the number of connections they have in the network. Therefore, one of the first advantages of using network visualisation is being able to immediately identify the most well-connected individuals in a network.

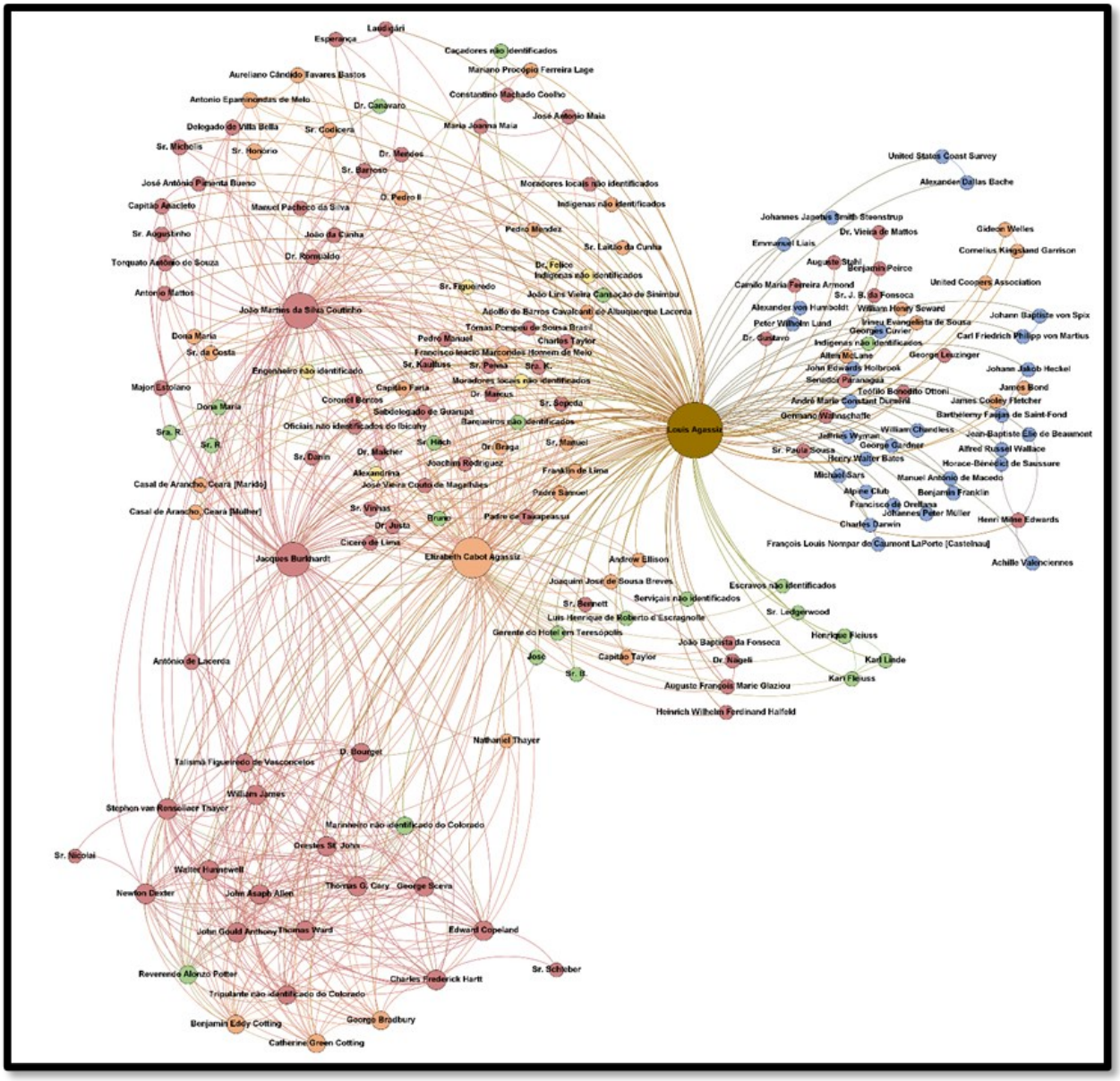

Figure 4. Visualisation of the network of people involved with the Thayer Expedition in Brazil. Source: Antunes (2015, p. 98).

Looking at the graph for the network in the Thayer Expedition we can clearly see that among the four major nodes one stands out for not having been part of the original members of the expedition that left the United States and arrived in Brazil. That node represents Major João Martins da Silva Coutinho, a military engineer who was experienced in travelling around the North and Northeast regions of Brazil and was appointed by Emperor Pedro II to accompany Agassiz acting as a guide and intermediary between naturalists and the local population. Because of this mediation, especially between travellers and the indigenous groups they encountered, Coutinho appears as one of the most well-connected individuals in the network. Able to speak *língua geral*[13], Portu-

[13] Literally meaning general language, it was a language based on the Tupi indigenous language and taught by Jesuit missionaries in Brazil to the many indigenous groups in the country in an attempt to communicate with them despite their many individual languages.

guese, French and probably some English, Coutinho was able to act as translator, thus allowing communication between the different groups met by travellers. Also, because of his experience travelling through some of the regions visited by the expedition, often on missions to map the country and study the natural productions of the land, Coutinho was friends with many local merchants, government, and military officials. The way Coutinho is represented in the graph allows us to illustrate concepts already used by historians, such as that of *go-between* (Raj, 2009), understood as an individual able to navigate through different cultural worlds. It's also interesting to notice that the graph translates the concept in a very literal way, as Coutinho is represented between the nodes which represent those individuals whom he connected.

Positions of nodes in a graph are decided according to algorithms chosen by the researcher. The algorithms read the information that has been put into the program and perform mathematical calculations based on them, combining mathematics with graph theory to represent information visually. For this graph, the algorithm used was Jacomy's Force Atlas 2 (Jacomy *et al.*, 2014), which reads a connection between two knots as a positive value, understanding it as an attraction. By positioning nodes with positive values close together, and pulling away nodes with negative values between themselves, meaning they are not connected, the algorithm is able to position nodes in the graph in a way that proximity means connection. Using this formula, the graph is then able to show communities of individuals who are closely linked together. An example of how communities are represented can be seen on figure 5, which represents the network of local individuals who collaborated with Henry Walter Bates' expedition to Brazilian Amazonia between 1848 and 1859. Once again, the historical document used to identify the nodes in this network was the naturalist's travel book, *The naturalist on the River Amazons*, published in two volumes in 1863. By comparing the communities shown in the graph with the information available on the travel book, we can realise that these communities are representing people who inhabited some of the same cities visited by the naturalist.

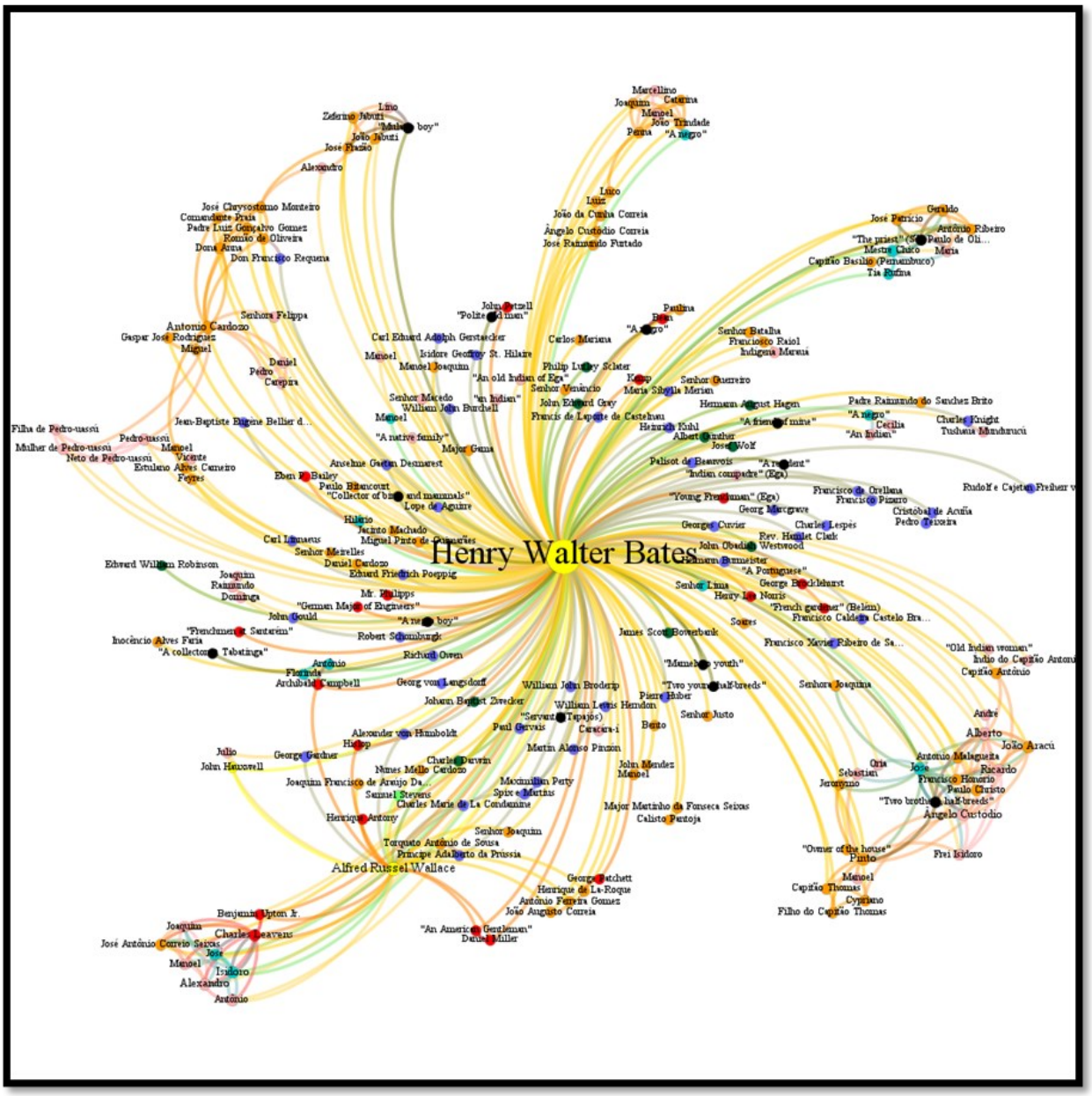

Figure 5. Visualisation of the network of people involved with Henry Walter Bates' expedition in Brazilian Amazonia. Source: Antunes (2019, p. 327).

Bates' expedition was chosen for the analysis due to its relation to Louis Agassiz and the Thayer Expedition. On the one hand, Bates is one of the naturalists most mentioned in Agassiz's travel book and the Swiss naturalist even brought a copy of Bates' narrative with him to Brazil. Whenever visiting a region previously visited by Bates, Agassiz would consult the British naturalist's experience and compare it to his own. On the other hand, there were significant differences between the two expeditions. Firstly, both Bates and Agassiz had opposing views on one of the most relevant questions 19th century naturalists proposed to answer. While Bates can be considered an early Darwinist, with his companion Alfred Wallace having presented his own views on evolution together with Darwin, Agassiz argued in favour of the catastrophist-creationist hypothesis which disregarded the possibility of organisms evolving. Not only did Bates and Agassiz had opposing views regarding evolution and the origin of species, but there was also great disparity in the infrastructure of their expeditions. While Agassiz had financial, institutional, and governmental support from

both the American and the Brazilian governments, Bates and Wallace arrived in the country with only around £100 and had to send specimens to be sold in England to be able to remain in the country.

The same methodology was used for the analysis and visualisation of both networks, taking as reference the travel books. This means that on both graphs every node represents an individual that was mentioned by the naturalists on their narratives. Again, it is important to realise that using the traveller's own words and descriptions of their experience means the network we are depicting is an image of the author's point of view. This means, for example, that they will always be the central node of their own network. However, even though we cannot fully escape the biases imprinted by the authors on their narratives, researchers have long learned from Italian historian Carlo Ginzburg (1989) to work from clues and evidence found sometimes in the fine details which we only get a glimpse of. Moreover, historians of science have been consistently and increasingly using travel books to find evidence to study the sociability of field work and analyse how travellers interacted with the local populations, as travellers were usually very detailed in their narratives.

Graphs made with social network visualisation tools allow us to better understand the importance of sociability to the fieldwork of 19th century naturalists, recognising that travellers on the move relied on a great number of collaborators. It also grants us a new way of looking at the information obtained from the historical sources, permitting a more comprehensive look of the social aspects of a scientific expedition. According to Antunes (2019), another advantage of applying SNA and network visualisation is:

> Social network analysis changes the focus of the research from an individual and biographical point of view to one that allows us to look at the interactions and relationships built by individuals in specific contexts, inserting the individual in those groups to which they belonged. Focusing on the plural, instead of the singular, allows us to consider the specific idiosyncrasies of the interactions which connect participants in a network, analysing what those moments of interaction meant not just for the individual, but for the entire network (p. 304, *translated for this article*).

Yet another advantage of network visualisation is being able to identify different groups with which naturalists interacted during their expeditions, which can be made by using different colours to represent each group. By using different colours to represent these groups we can immediately have a sense of the diversity of Bates' network, which had a total of 221 individuals identified from the information available on the book. The different colours allow us to identify groups more easily with whom the naturalist had the most contact with, such as the yellow nodes which represent the Brazilian elite. Also, by looking at the most prominent colours which make up a community we could identify the main groups the naturalist interacted with in each region visited. This could allow the identification of regions in which contact with indigenous groups was more frequent, or cities in which there were a larger number of foreign residents, for instance.

These examples show the many possibilities of social network analysis and visualisation in the History of Science. The graphs for Louis Agassiz's and Henry Walter Bates' expeditions highlight how 19th century scientific expeditions relied on hundreds of individuals from diverse backgrounds

who contributed to making these expeditions possible. While some provided aid with the logistics of moving around a country that was unknown to the foreign traveller, others contributed directly with the scientific tasks of collecting, preserving, and preparing specimens to be shipped back to museums and scientific societies abroad. While this is all described in the travel book, taking the information from its original historical text, and introducing it to a software like Gephi allows us to take a new look at the data and, therefore, at the very group of people that it describes. Graphical analysis, in this case, was an important complementary stage of understanding the sociability of 19th century scientific expeditions.

3. CONCLUSION

Gephi and other network visualisation tools can be used by historians of science to translate information obtained from historical documents into graphics, allowing for a different approach to data. The possibilities for using this methodology in the History of Science are endless, as Gephi permits researchers to adjust the graph to different types of visualisations, which can be used according to the objectives of the research. Social network analysis, together with the recent consolidation of Digital Humanities as a field, means that tools like Gephi should become more readily available for historians and researchers in other areas. For historians of science, being able to visualise networks can be a great way of renovating and deepening our understanding of science as a social and collaborative practice.

Particularly in the analysis of sociability in 19th century scientific expeditions, visualising the networks of individuals who participated in Agassiz's and Bates' expeditions revealed that graphical analysis can not only allow us to look at the information obtained from historical sources in a different way, but also makes clear that both naturalists relied on an enormous number of local collaborators during their travels in Brazil, which helps us understand how interacting with local groups was a fundamental part of science practiced in the field. Also, social network visualisation can be a valuable tool for communicating the results obtained from historical analysis both to specialised and non-specialised audiences.

By allowing anyone who looks at the graph to identify that there are individuals more prominently represented than others, since their nodes can be much bigger compared to the other circles in the image, the graph can provoke questions such as why certain individuals have been more active than others in the network. For historians, this means being able to graphically translate concepts, such as that of go-between, emphasising how intermediaries were valuable additions to a foreigner's network in another country, especially because they helped navigate and translate through different cultural and linguistic worlds.

Finally, applying Gephi to the analysis of the networks of both Agassiz and Bates in Brazil has allowed us to better understand how scientific work in the field was a social and collaborative practice, which meant that naturalists had to mobilise hundreds of people, many of them who were not scientists themselves, to accomplish their scientific objectives. This has helped us demystify the

idea of travellers as lone and heroic adventurers who bravely faced many perils for the advancement of science.

BIBLIOGRAPHIC REFERENCES

Agassiz, L., and Agassiz, E. C. (1868). *A Journey in Brazil*. Ticknor and Fields. https://archive.org/details/journeyinbrazil00agasiala

Antunes, C. (2012). A história da análise de redes e a análise de redes em história. *História, Revista da Faculdade de Letras da Universidade do Porto*, *2*(IV), 11-22. http://ler.letras.up.pt/uploads/ficheiros/11313.pdf

Antunes, A. P. (2015). *A rede dos invisíveis: uma análise dos auxiliaries na expedição de Louis Agassiz ao Brasil (1865-1866)*. (Dissertação do Mestrado em História das Ciências e da Saúde). Casa de Oswaldo Cruz, Fundação Oswaldo Cruz. http://www.ppghcs.coc.fiocruz.br/images/dissertacoes/dissertacao_anderson_antunes.pdf

Antunes, A. P. (2019). *Um naturalista e seus colaboradores na Amazônia: a expedição de Henry Walter Bates ao Brasil (1848-1859)*. (Tese do Doutorado em História das Ciências e da Saúde). Casa de Oswaldo Cruz, Fundação Oswaldo Cruz. http://ppghcs.coc.fiocruz.br/images/dissertacoes/teste/tese_anderson_antunes.pdf

Bates, H. W. (1863). *The naturalist on the River Amazons. A record of adventures, habits of animals, sketches of Brazilian and Indian life, and aspects of nature under the Equator, during eleven years of travel (vol. I)*. John Murray. https://archive.org/details/naturalistonrive01bate

Bates, H. W. (1863). *The naturalist on the River Amazons. A record of adventures, habits of animals, sketches of Brazilian and Indian life, and aspects of nature under the Equator, during eleven years of travel (vol. II)*. John Murray. https://archive.org/details/naturalistonrive02bate

Bradford, W. C. (2004). Reaching the Visual Learner: Teaching Property through Art. *The Law Teacher*, *11*. https://papers.ssrn.com/sol3/papers.cfm?abstract_id=587201

Camerini, J. (1997). Remains of the day: early Victorians in the field. In B. Lightman (Ed.), *Victorian science in context* (pp. 354-377). The University of Chicago Press.

Center for History and Economics. Harvard University. (2017). Method. *Visualizing Historical Networks*. http://histecon.fas.harvard.edu/visualizing/index.html#4

Chen, L. (Ed.). (2020). *A journey of discovering Sociology: what Sociology is in 20 contemporary American sociologists' eyes*. Peking University Press.

Farley, J., and Geison, G. L. (1994). Ciencia, política y generación espontánea en la Francia del siglo diecinueve: el debate Pasteur-Pouchet. In C. Solís, *Razones e intereses. La historia de la ciencia después de Kuhn* (pp. 219-263). Paidós.

Fleck, L. (2010 [1935]). *Gênese e Desenvolvimento de um Fato Científico: Introdução à doutrina do estilo de pensamento e do coletivo de pensamento*. Fabrefactum Editora.

Ginzburg, C. (1989). *Mitos, emblemas, sinais: morfologia e história*. Companhia das Letras.

Gold, M. K. (Ed.). (2012). *Debates in the Digital Humanities*. University of Minnesota Press.

Heymann, S. (2010). Gephi initiator interview: how "semiotics matter". *Gephi blog*. https://gephi.wordpress.com/2010/02/01/gephi-initiator-interview-how-semiotics-matter/

Jacomy, M., Bastian, M., and Heymann, S. (2009). Gephi: An Open-source Software for Exploring and Manipulating Networks. In Association for the Advancement of Artificial Intelligence, *Proceedings of the Third International AAAI Conference on Weblogs and Social Media*. https://www.aaai.org/ocs/index.php/ICWSM/09/paper/view/154

Jacomy, M., Venturini, T., Heymann, S., and Bastian, M. (2014). ForceAtlas2, a Continuous Graph Layout Algorithm for Handy Network Visualization Designed for the Gephi Software. *PLoS ONE*, *9*(6), e98679. https://doi.org/10.1371/journal.pone.0098679

Kuhn, T. (1998 [1962]). *A estrutura das revoluções científicas*. Editora Perspectiva.

Luke, D. A., and Harris, J. K. (2007). Network Analysis in Public Health: History, Methods, and Applications. *The Annual Review of Public Health,* (28), 69-93. https://www.annualreviews.org/doi/pdf/10.1146/annurev.publhealth.28.021406.144132

Ma, K-L., Liao, I., Frazier, J., Hauser, H., and Kostis, H-N. (2012). Scientific Storytelling Using Visualization. *IEEE Transactions on Visualization and Computer Graphics*, *32*(1), 12-19. https://ieeexplore.ieee.org/document/6111347

Mathias, C. L. K. (2014). Análise de rede social. *Revista Internacional Interdisciplinar INTERthesis*, *11* (1), 131-146. http://dx.doi.org/10.5007/1807-1384.2014v11n1p131

Moreira, I. de C. (2002). O escravo do naturalista. *Ciência hoje*, *31*(184), 41-48. http://www.casadaciencia.ufrj.br/caminhosdedarwin/downloads/escravo.pdf

Moreno, J. L. (1934). *Who shall survive? A new approach to the problem of Human interrelations*. Nervous and Mental Disease Publishing Co.

Otte, E., and Rousseau, R. (2002). Social network analysis: a powerful strategy, also for the information sciences. *Journal of Information Science*, *28*(6), 441-453. https://journals.sagepub.com/doi/abs/10.1177/016555150202800601

Padgett, J. F., and Ansell, C. K. (1993). Robust Action and the Rise of the Medici, 1400-1434. *American Journal of Sociology*, *98*(6), 1259-1319. https://www.jstor.org/stable/2781822

Pandolfi, F. C., and Bueno, N. P. (2014). Análise de redes sociais em História: noções básicas e sugestões de aplicação. In *Anais do XIX Encontro Regional de História. Juiz de Fora, 28 a 31 de julho de 2014* (pp. 1-11). http://www.snh2011.anpuh.org/resources/anais/34/1401385226_ARQUIVO_anpuhpaper29-05corrigido.pdf

Pratt, M. L. (1999). A crítica na zona de contato: nação e comunidade fora de foco. *Travessia*, (38), 7-29. https://periodicos.ufsc.br/index.php/travessia/article/download/14665/13434

Raj, K. (2009). Mapping knowledge go-betweens in Calcutta, 1770-1820. In S. Schaffer, L. Roberts, K. Raj, and J. Delbourgo (Eds.), *The brokered world. Go-Betweens and Global Intelligence, 1770-1820* (pp. 105-150). Science History Publications.

Stanford University. (2013). *Mapping the Republic of Letters*. http://republicofletters.stanford.edu/

Subrahmanyam, S. (1996). *Merchant Networks in the Early Modern World, 1450-1800*. Variorum.

Vermelho, S. C., Velho, A. P. M., and Bertoncello, V. (2015). Sobre o conceito de redes e seus pesquisadores. *Educação e Pesquisa*, *41*(4), 863-881. http://dx.doi.org/10.1590/s1517-97022015041612

Zacks, J., Levy, E., Tversky, B., and Schiano, D. (2002). Graphs in Print. In M. Anderson, B. Meyer, and P. Olivier (Eds.), *Diagrammatic Representation and Reasoning* (pp. 187-206). Springer. https://doi.org/10.1007/978-1-4471-0109-3_11